

The Magnetic Response of Cuprate Superconductors

Scientific Achievement

The magnetic response of cuprate superconductors has been calculated using linear response theory for a d-wave superconductor, with a single-particle dispersion based on angle resolved photoemission data. These calculations can explain many of the unusual properties of the cuprates observed by inelastic neutron scattering. In particular, they predict a magnetic dispersion that is incommensurate at low energies, commensurate at an intermediate energy, and incommensurate again at high energies. This novel “hourglass” dispersion is a unique signature of the experimental data. These calculations can also explain the “twist” in the hourglass that is also seen experimentally, where the dispersion pattern in momentum space rotates by 45 degrees from a bond centered pattern at low energies to a diagonal one at high energies.

Moreover, the calculations have revealed that the low energy dispersion forms a collective mode with an unusual “reversed magnon” dispersion (reversed in the sense that the commensurate point is at the top of the dispersion branch). More interestingly, they also reveal the high energy dispersion forms a new dispersive branch that is separated in momentum and energy from the low energy dispersive branch. This behavior is consistent with very recent experimental studies on the cuprate superconductor YBCO by groups at Oak Ridge and at Saclay.

Significance

The success of these calculations gives strong support for a picture of the cuprates that involves magnetically correlated electrons with a well-defined two-dimensional Fermi surface and a d-wave superconducting energy gap. Moreover, this success also illustrates the consistency of angle-resolved photoemission data with inelastic neutron scattering data. This builds on our earlier success of describing the dispersion in photoemission spectra as due to the interaction of the electrons with the magnetic degrees of freedom, which as we have now shown in the present work can in turn be used to calculate these same magnetic degrees of freedom. Having also shown recently the consistency of photoemission and infrared conductivity data, a picture is now emerging which unifies all of these three data sets. One of the challenges in the future will be to address scanning tunneling microscopy data to find its relationship to the other data. Moreover, very recent neutron data have indicated a similar magnetic dispersion for a non-superconducting cuprate. So, another challenge will be to describe these new data with a similar formalism, which we anticipate will involve incorporating a d-wave pseudogap into the calculations.

This work has been presented in two papers in Physical Review B, and a new paper published last year in Physical Review Letters. It was recognized by an invited talk at the 2005 March Meeting of the American Physical Society.

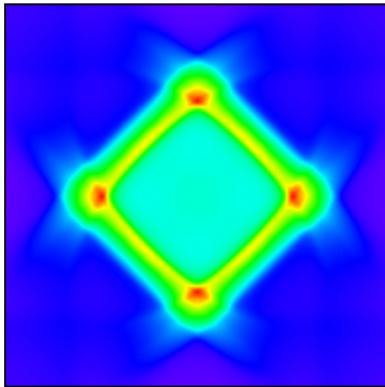
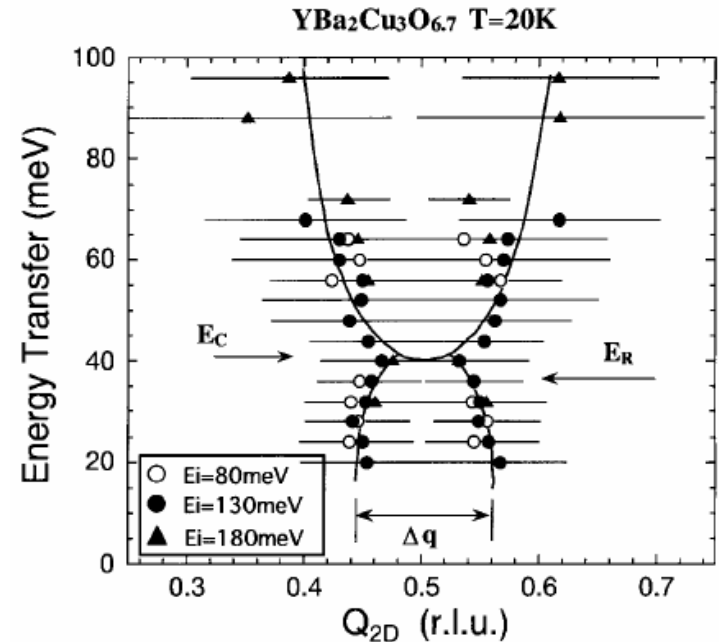
Performers

Michael R. Norman (ANL-MSD)

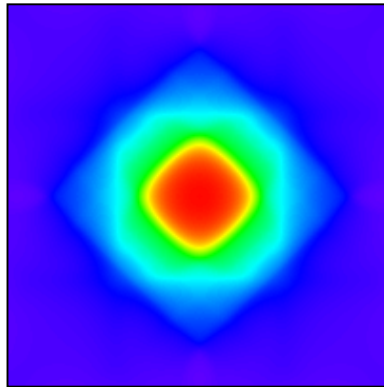
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Cuprate superconductors are characterized by an unusual “hourglass” magnetic dispersion as seen by inelastic neutron scattering (right panel). This behavior is found by us in linear response calculations for a d-wave superconductor based on the two-dimensional Fermi surface seen by angle resolved photoemission (panels below).

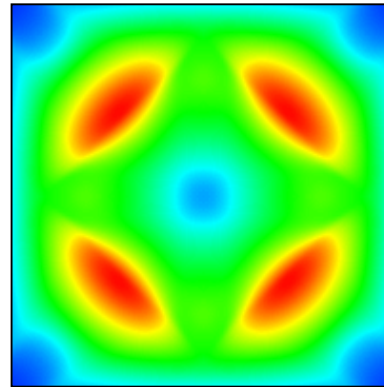
The challenge for the future will be to extend these studies to non-superconducting cuprates that possess a pseudogap.



below resonance



at resonance



above resonance

Above - magnetic dispersion in a cuprate superconductor

Left - calculated momentum pattern at low, medium, and high energies for YBCO